ARI Contractor Report 2004-03

Perspectives On Studying Collaboration In Distributed Networks

Karol G. Ross
Klein Associates Inc.

January 2004

United States Army Research Institute for the Behavioral and Social Sciences

REPORT DOCUMENTATION PAGE

1. REPORT DATE (dd-mm-yy)	2. REPORT TYPE	3. DATES COVERED (from. . . to)
January 2004	Final	April 2002 – August 2003

4. TITLE AND SUBTITLE	5a. CONTRACT OR GRANT NUMBER
Perspectives On Studying Collaboration In Distributed Networks	DASW01-02-P-0526
	5b. PROGRAM ELEMENT NUMBER 622785
6. AUTHOR(S)	5c. PROJECT NUMBER A790
Karol G. Ross	5d. TASK NUMBER 209
	5e. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Klein Associates Inc. 1750 Commerce Center Blvd. N Fairborn, OH 45324-6362	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Institute for the Behavioral and Social Sciences 5001 Eisenhower Avenue ATTN: DAPE-ARI-II Alexandria, VA 22304-4841	10. MONITOR ACRONYM ARI 11. MONITOR REPORT NUMBER Contractor Report 2004-03

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

This report is published to meet legal and contractual requirements and may not meet ARI's scientific and/or professional standards for publication.

14. ABSTRACT *(Maximum 200 words)*:

This report describes cognitive variables and frameworks that are useful in the investigation of network collaboration in Army environments. Network collaboration is currently under study by the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) in the context of performance in a simulated network task using the game SCUDHunt. SCUDHunt was developed by ThoughtLink, Incorporated for the Defense Advanced Research Projects Agency (DARPA). The use of SCUDHunt does not constitute endorsement of the product by ARI, the U.S. Army or the U.S. Department of Defense. Key variables that facilitate functioning in this simulated network environment are discussed, based on the results of interviews with proficient SCUDHunt players. Frameworks for examining the data from the SCUDHunt studies are presented. Finally, brief recommendations for the directions of future research in this domain are presented.

15. SUBJECT TERMS

Cognitive Task Analysis, Collaboration, Communication Classification, Distributed Teamwork, Net-Centric, Network-Centric, SCUDHunt, Situational Awareness

SECURITY CLASSIFICATION OF			19. LIMITATION OF ABSTRACT	20. NUMBER OF PAGES	21. RESPONSIBLE PERSON
16. REPORT	17. ABSTRACT	18. THIS PAGE			
Unclassified	Unclassified	Unclassified	Unlimited		Dr. Brooke B. Schaab (757) 836-3986

Purpose

The purpose of this report is to describe cognitive variables and frameworks that are useful in the investigation of network collaboration in Army environments. Network collaboration is currently under study by the U. S. Army Research Institute in the context of performance in a simulated network task using the SCUDHunt* game, developed by DARPA, as part of a study of distributed situational awareness (Perla, Markowitz, Nofi, Weuve, Loughran, & Stahl, 2000). Key variables that facilitate functioning in this environment will be discussed, based on the results of interviews with proficient SCUDHunt players. Frameworks for examining the data from the SCUDHunt studies are also presented. Finally, brief recommendations for the directions of future research in this domain are presented.

These perspectives on collaboration research are documented in response to the need to better understand the emerging networked organizations in the Army (Alberts, Garstka, & Stein, 1999). In the battlefields where today's soldiers apply their skills, communication is both more complex and more important than ever before. Military operations are widely distributed over space and time, and this necessitates a similar distribution for the individuals involved in those operations. There can be no argument that collaboration and shared understanding of the battlespace are required for effective functioning between units in this situation, but the individual skills that support this process are not well understood. What skills influence the success or failure of communication between soldiers? When these skills are identified, what steps must be taken in order to facilitate individuals to become team members who are fluent in the effective methods of network collaboration? These skills are crucial for the U.S. Army's forces to maintain their current level of information and technical superiority.

Communication may take place on the battlefield under a variety of circumstances, and with varying goals. Using network resources for collaboration purposes has become a particularly attractive option, because of their versatility and the possibility for rapid delivery of text and graphic files, such as fragmentary orders and tactical maps. There are also potential pitfalls associated with a network-based method of communication, though. Many soldiers may be unfamiliar with the technology, or the technology may be non-intuitive and difficult to use; the necessary hardware and software may not be entirely reliable; time pressure may preclude the use of certain methods of network communication, because of delays in transfer. But, most important, soldiers may just not be skilled in how to collaborate in this type of environment. This is a high-stakes environment and the skill to use the emerging technologies must include highly honed collaboration skills. Research to understand the variables in network collaboration is critical to support the development of training for collaboration skills.

* The use of SCUDHunt does not constitute endorsement of the product by ARI, the U.S. Army or the U.S. Department of Defense.

Understanding Collaboration

Cognitive Task Analysis

One method for exploring the skills that will be needed in network-collaborative environments is Cognitive Task Analysis (CTA). CTA is a set of techniques (e.g., Klein, Calderwood, & MacGregor, 1989) that were designed to take advantage of the experience of a subject-matter expert (SME) in order to understand a complex process, job, or task. Especially in situations where time pressure, high stakes, and ambiguity of information are present, CTA allows the researcher to probe the experiences of the expert for insights into exactly how critical decisions were made. In the context of network collaborations, experts who have used the relevant technology many times, under the environmental conditions of interest, can provide valuable information about what makes this process difficult and where attention must be focused in order to improve performance, all from a user's point of view.

It is difficult to find such expertise as these environments are only now emerging in response to changing missions and technologies. To envision this new battlefield, the SCUDHunt game is being used to simulate that environment. To understand the collaboration skills that may be needed in the new battlefield environment, Klein Associates conducted a CTA using researchers who were proficient at collaborating in the SCUDHunt context. The purpose of the CTA was to suggest the types of collaboration skills that should be considered when the SCUDHunt data are analyzed.

Task Diagram

A Task Diagram (Militello, Hutton, & Miller, 1996; Militello, Hutton, Pliske, Knight, & Klein, 1997) was used first to lay out the major tasks in the simulated environment and to identify which tasks are most cognitively challenging. Three experienced SCUDHunt players were interviewed to determine the primary tasks in playing the game. The interviewees were asked to come up with three to six main tasks that cover the performance in the game and then to indicate which of these tasks were the most cognitively challenging. Later, the results of the Task Diagram were compiled into one graphic representation reflecting the input from all three interviews, and this Task Diagram was reviewed with the interviewees before finalization.

The final Task Diagram synthesizing the interviews with three proficient SCUDHunt players is shown in Figure 1. Twelve tasks were identified as comprising SCUDHunt performance:

- Know own and partner's assets
- Generate own plan for asset placement
- Coordinate own plan with partner's plan

- Deploy own assets
- Remember where assets are deployed
- Look at shared results of intelligence gathering
- Coordinate to find out which assets were used by the partner to understand results
- Consider reliability of assets to assess results
- Consider any previous intelligence and interpretations
- Generate own Strike Plan
- Input Strike Plan and get results
- Generate new asset placement plan to refine conclusions.

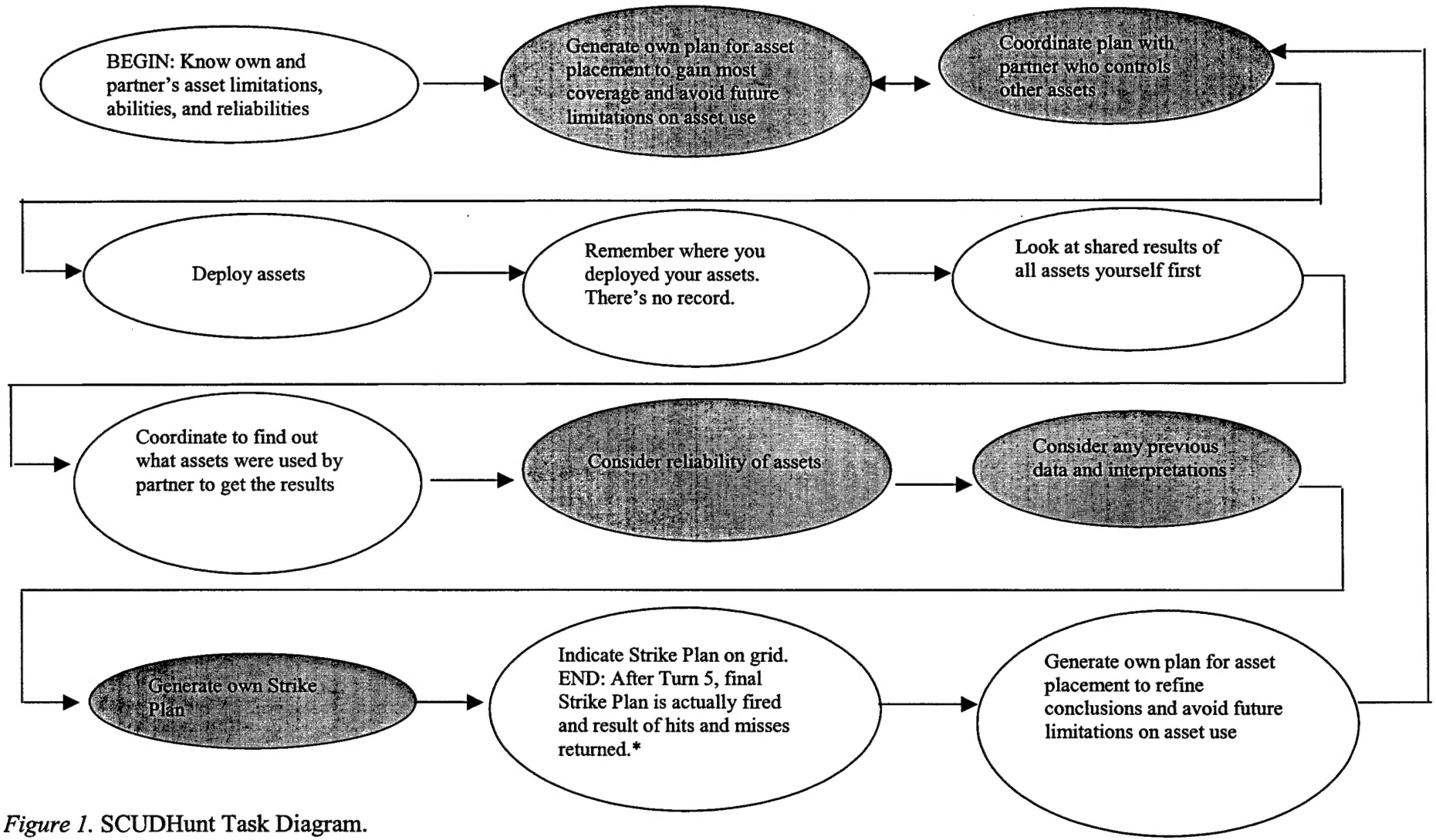

Figure 1. SCUDHunt Task Diagram.

Denotes a task that requires difficult or complex cognitive skills---judgments, assessments, problem-solving skills, or thinking skills.

* Strike Plans plotted on the grid for turns 1-4 only indicate player's conclusions at that time and are not actually fired.

Of the 12 SCUDHunt tasks, 5 were identified by the interviewees as cognitively challenging. These tasks include the following:

- Generate own plan for asset placement
- Coordinate own plan with partner's plan
- Consider reliability of assets to assess results
- Consider any previous intelligence and interpretations
- Generate own Strike Plan

Knowledge Audit

A Knowledge Audit (Klein & Militello, in press) was used to further assess the five tasks that were identified as cognitively challenging to understand the nature of the challenges and the collaborative aspects of the tasks. The Knowledge Audit consists of a set of probes designed to extract expertise along a number of dimensions: understanding the big picture, noticing important cues, strategies for working smart, noticing opportunities for success, and self-monitoring. The interview is based on obtaining examples of each of these dimensions and probing to understand the cues and strategies the proficient or expert performer uses, as well as what they believe makes the task difficult for the novice.

The results of the three interviews were compiled into one Knowledge Audit table and the strategies, cues, and difficulties were reviewed to see what cognitive skills and functions were indicated based on the frameworks reviewed below. The following tasks were combined in the final table of interview results, because the findings were so intertwined: consider reliability of assets to assess results, consider previous intelligence, and generate own Strike Plan. The findings are displayed in Appendix A.

Cognitive Frameworks for Understanding Collaboration Behaviors

Three sources were used as potential categorizations of cognitive functions. These frameworks are shown in Appendix B. The first source is a report from a cognitive testing project that was conducted for the Navy (O'Donnell, 2001). A cognitive model and a final list of cognitive functions for the project are shown. The second is the list of training cognitive objectives that were generated for team decision skills training for firefighters (Harris, Malek, Ross, & Thordsen, 2002). The third is a matrix of cognitive skills generated as part of a situation awareness project (Klein, 2001).

When the results of the CTA and the cognitive frameworks were combined, a list of tasks, skills, and functions was generated. These are shown in Table 1 below.

Table 1

Cognitive Elements in SCUDHunt Performance

Cognitive Tasks

- Understand own capabilities (systems and personnel)
- Envision goals and plans
- Define roles and functions
- Understand enemy capabilities and behaviors
- Assess the situation
- Balance immediate concerns and longer term objectives
- Compensate to fill gaps in team performance

Cognitive Skills

- Managing attention
- Discriminating cues and patterns
- Constructing mental models of cause and effect (interpret information)
- Building a story from incomplete information
- Decentering (understand how own actions affect partner)
- Monitoring one's own performance (e.g., avoiding fixation, avoiding over-emphasis on most recent information, realizing when expectancies have been violated)

Cognitive Functions

- Perceptual processing
- Short-term memory (to maintain overall picture of search area and to hold procedural and declarative knowledge)*
- Working memory

* In this case, declarative and procedural knowledge are not retrieved from long-term memory for use in working memory, but are all held in short term memory while other skills/functions are executed. Memory aids (cheat sheets) are used to support short-term memory.

Communication and Distributed Teamwork Frameworks for Understanding Collaboration

Team Communication Variables

A communication framework was suggested as a manner of investigating collaboration behaviors evidenced in SCUDHunt. The framework was organized to facilitate a content analysis of the SCUDHunt data. Content analysis is "a research technique for making inferences by systematically and objectively identifying specified characteristics within a text" (Stone, Dunphy, Smith, & Ogilvie, 1966). For those interested in exploring communication, content analysis allows for the examination and identification of messages found in a text. Content analysis was a very popular method of analyzing public and mass mediated communication in the 1970s and 1980s when hundreds of journal articles on television programming and political communication were published using this methodology (Comstock, 1975; Jackson-Beeck & Kraus, 1980).

The main goal of content analysis is to describe the characteristics of messages embedded in texts. Krippendorf (1980) identified four advantages to content analysis. First, it is unobtrusive because it studies texts that already exist. Second, it accepts unstructured material, which observers categorize. There is no need for structured interviews or questionnaires. Third, content analysis allows a researcher to study data within a context. Last, it is able to handle massive amounts of data.

One type of content analysis is a conversation analysis. Conversation analysis examines messages exchanged during dyadic or small group interactions in order to discover the "systematic and orderly properties which are meaningful to conversants [and researchers]" (Heritage, 1989). The basic process of conversational analysis is to obtain conversation data, transcribe from oral to written form, develop coding schemes, categorize messages into schemes, analyze codings to describe and draw inferences about the content, structure, or effects of conversation, and report the findings.

It should be noted that suggestions and criticisms have been made about the reliability and objectivity of content analysis. Specifically, Kolbe and Burnett (1991) suggest that objectivity of content analysis studies can be improved by precise definitions and operational rules and by utilizing coders that are independent of both the authors of the research and each other. They go on to suggest that the method for determining intercoder reliability should be documented in the research.

A framework for performing a content analysis of the SCUDHunt data is shown in Appendix C. It includes variables associated with "Task Roles," "Team Maintenance Roles," and "Self-Oriented Behaviors." In addition to Appendix C providing a framework, it also includes part of the SCUDHunt data coded into the appropriate categories as a sample of how the analysis could be carried out.

There are generally two types of roles individuals need to take on to make a team function in a collaborative manner—those concerned with completing the team's tasks

and those concerned with the social and emotional needs of the group (Ketrow, 1991). Both types of roles are essential to an effective team. Task roles are concerned with getting the job done. Those who function in task roles help move the group toward its goal and help the group be adaptable to needs and changes along the way. Maintenance roles are concerned with the team getting along, and focus on developing ways to express and deal with emotional dimensions of working in a group. In addition, there are self-centered roles that are identified as when individuals focus on their own needs, which detracts from collaboration. Most effective team members will be able to adapt to take on a variety of these roles as needed (and avoid the self-centered behaviors) to keep the team functioning effectively. The categories for the coding scheme are derived from Hare (1994) and Ketrow (1991).

To carry out the content analysis, a minimum of four coders should be used. There should be an equal division of men and women to control for gender differences in perception of behaviors. Each should be trained in the coding procedures. They should be given a coding sheet along with an explanation of the procedures. They should be questioned to determine their understanding of these procedures. Together, coders should conduct a mock analysis of one interaction. Then coders should code a second interaction separately. After completing this interaction, coders should meet to discuss their degree of agreement. After the initial training, coders should be assigned to code interactions separately. Of these interactions, two should overlap to serve as a measure of intercoder reliability.

Distributed Teamwork

From our work with distributed teams (Wiggins & Klinger, 2001) we compiled a number of challenges or points at which distributed teamwork can break down. These are exchanges of information, goal conflicts, synchronization overhead, diagnostic overhead, building and maintaining situation awareness, distributing situational awareness, and rigidity. We used these elements to construct another matrix that could be used to analyze the collaborative exchanges during SCUDHunt. This matrix is shown in Appendix D. The matrix also provides an example of some of the SCUDHunt data coded into these categories.

Future Research

Future research must examine the behaviors of trained personnel collaborating in rich contexts. Instances of the distributed teamwork breakdowns discussed above must be captured and analyzed to understand the gaps in performance. It is very likely that for lower-level soldiers to be good collaborators, they will require training that quickly strengthens their tactical thinking skills even at lower ranks and echelons so they can recognize what is important to report. We must also increase their awareness of key areas in which distributed teamwork can break down, and train behaviors to monitor and repair such breakdowns. This may include training in task roles, team maintenance roles, and self-monitoring roles indicated in the research frameworks discussed here.

References

Alberts, D. S., Garstka, J. J., & Stein, F. P. (1999). *Network centric warfare: Developing and leveraging information superiority*. Washington, D.C.: C4ISR Cooperative Research Program (CCRP).

Comstock, G. (1975). *Television and human behavior: The key studies*. Santa Monica, CA: Rand Corporation.

Hare, A. P. (1994). Types of roles in small groups. *Small Group Research, 25*(3), 433-448.

Harris, D., Malek, D. A., Ross, K. G., & Thordsen, M. L. (2002). *Developing a scenario-based training pedagogy for distributed teams* (Final Report for Contract #F33615-02-M-6011 prepared for the Air Force Research Laboratory, Mesa, AZ). Fairborn, OH: Klein Associates Inc.

Heritage, J. (1989). Current development in conversation analysis. In D. Roger & P. Bull (Eds.), *Conversation: An interdisciplinary perspective*. Clevdon, England: Multilingual Matters.

Jackson-Beeck, M., & Kraus, S. (1980). Political communication theory and research: An overview 1978-1979. In D. D. Nimmo (Ed.), *Communication yearbook 4*. New Brunswick, NJ: Transaction Books.

Ketrow, S. M. (1991). Communication role specializations and perceptions of leadership. *Small Group Research, 22*(4), 492-514.

Klein, G., & Militello, L. (in press). The knowledge audit as a method for cognitive task analysis. In H. Montgomery, R. Lipshitz & B. Brehmer (Eds.), *How professionals make decisions*. Mahwah, NJ: Lawrence Erlbaum Associates.

Klein, G. A. (2001). *A distributed decision training environment for improving situation awareness* (Final Report for Subcontract PO #20838 (ISX) and Prime Contract #DASW01-01-C-0009 (Army)). Fairborn, OH: Klein Associates.

Klein, G. A., Calderwood, R., & MacGregor, D. (1989). Critical decision method for eliciting knowledge. *IEEE Transactions on Systems, Man, and Cybernetics, 19*(3), 462-472.

Kolbe, R. H., & Burnett, M. S. (1991). Content analysis research: An examination of applications with directives for improving research reliability and objectivity. *Journal of Consumer Research*.

Krippendorf, K. (1980). *Content analysis: An introduction to its methodology*. Newbury Park, CA: Sage.

Militello, L. G., Hutton, R. J. B., & Miller, T. E. (1996). Applied Cognitive Task Analysis [Computer software]. Fairborn, OH: Klein Associates Inc.

Militello, L. G., Hutton, R. J. B., Pliske, R. M., Knight, B. J., & Klein, G. (1997). *Applied Cognitive Task Analysis (ACTA) Methodology* (Technical Report prepared for Navy Personnel Research and Development Center No. Contract No. N66001-94-C-7034). Fairborn, OH: Klein Associates Inc.

O'Donnell, R. D. (2001). *Comprehensive computerized cognitive assessment battery* (Final Report for Contract N00140-01-M-0064 prepared for Office of Naval Research, Arlington, VA). Dayton, OH: NTI, Inc.

Perla, P. P., Markowitz, M., Nofi, A., Weuve, C., Loughran, J., & Stahl, M. (2000). *Gaming and shared situation awareness*. Alexandria, VA: Center for Naval Analysis.

Stone, P. J., Dunphy, D. C., Smith, M. S., & Ogilvie, D. M. (1966). *The general inquirer: A computer approach to content analysis*. Cambridge, MA: MIT Press.

Wiggins, S. L., & Klinger, D. W. (2001). *Modeling and applying distributed training for multi-platform naval air missions* (Final Option Task Summary Report for Contract N613399-98-C-0062, NAWCTSD, Orlando, FL). Fairborn, OH: Klein Associates Inc.

Appendix A

Knowledge Audit of SCUDHunt Proficiencies

SCUDHunt Combined Knowledge Audit

Task: GENERATE OWN PLAN FOR ASSET PLACEMENT

Probe	Example	Cues & Strategies	Why Difficult?
Big Picture – Can you give me an example of what is important about the Big Picture for the task of planning your asset placement? What are the major elements you have to know and keep track of? Interview: MS	When you know where two of the three targets are already and you need to concentrate your efforts on getting information about the third target before deploying assets. -Envision goals and plans. -Manage attention. -Assess the situation.	False positives are possible (indication of a target, but the source is unreliable so target is not actually there). So even a positive ID should be double-checked by a more reliable source. -Understand own capabilities. Question mark (as the information reported by an asset over an area) is not very helpful, but you need to look at anything other than a blank section or "O" (nothing to report). -Discriminate cues and patterns. -Manage attention. You can accumulate trends on paper, but it is better to learn to hold the findings over time in your mind. -Build a story from incomplete information. Accumulate the findings by flipping through the different results (one result page per turn is shown on the screen and you	A lot of people identify what they believe to be "black and white" info and focus on it. They believe a report that looks "clear" even when the asset is not reliable and they have been told it was not totally reliable during training. -Discriminate cues and patterns. -Manage attention. -Monitor own performance (to avoid fixation). The enemy can put out decoys and the novice will believe that a red X derived from a decoy is a clear-cut sign that a target is there and fixate on it early on in the game. -Understand enemy capabilities and behaviors. -Monitor own behavior to avoid fixation. -Discriminate cues and plans. Novices first focus on seemingly solid information and make internal decisions early in the game (1st or 2nd

Yellow indicates cognitive task, function, or skill.

Probe	Example	Cues & Strategies	Why Difficult?
		can only see one at a time on the screen). -Build a story from incomplete information.	turn). -Manage attention. -Monitor own performance to avoid fixation. Novices can become overwhelmed with paper as they try to keep a paper record of the game. -Manage attention. -Discriminate what cues and patterns are important so as to manage information overload. Novices focus on just the current turn and tend to use less of the information available. -Manage attention. -Monitor own performance to avoid fixation and look for violations of expectancies in existing story. -Discriminate cues and patterns across time.
Noticing—Have you had experiences during planning asset deployment when a part of the situation just "popped out" at you? Interview: MS	In the game yesterday when I knew I had to send in a second asset into an area. -Understand own capabilities.	I knew I needed to use something with higher reliability to verify the findings. -Understand own capabilities.	The ground asset -HUMINT cannot return any information on any turn in which he has just been moved. Novices are told this in pre-game training, but over and over will keep moving that very reliable asset every

Yellow indicates cognitive task, function, or skill.

Probe	Example	Cues & Strategies	Why Difficult?
			turn, thus getting no information at all from it. -Understand own capabilities. Novice doesn't think in terms of using a second more reliable asset. -Understand own capabilities.
Job Smarts – When you plan for asset deployment, are there ways of working smart or accomplishing more with less that you have found especially useful? Interview: MS	When I learned that ground assets are restricted in movement, but reliable. -Understand own capabilities.	Know the limits on ground assets or you'll restrict their movement in future turns. -Understand own capabilities. Know the limits on ground assets or you will lose information when you only have 5 turns. If you move on turns 1 and 3, you only get information on turns 2 and 4. If you wait to move on turn 2 and 4, you get information on turns 1, 3, and 5. -Understand own capabilities. -Envision goals and plans.	Novices don't plan the use of the reliable assets well. -Envision goals and plans. They don't know the consequences of poor planning for highly reliable assets. -Envision goals and plans.
Job Smarts – When you plan for asset deployment, are there ways of working smart or accomplishing more with less that you have found especially useful? Interview: FJ	In the middle of the game (say turn 3), you should have a coordinated search plan going on with your partner. -Envision goals and plans. -Define roles and functions.	One partner searches edges and one searches middle of search area. -Define roles and functions. -Envision goals and plans. An expert will know their assets well, that is, how to control them and their reliability.	Novice doesn't know what partner's assets can do even with training. -Understand own capabilities. Must concentrate on what assets can really do. Novices assume for example that ground can have the same kind of coverage

Probe	Example	Cues & Strategies	Why Difficult?
		-Understand own capabilities. Air assets cover the top half of the map best. -Understand own capabilities. Ground assets cover the edges of the border well due to their limits. -Understand own capabilities.	as air. -Understand own capabilities. Novices don't coordinate. -Understand own capabilities. -Define roles and functions. Novices don't realize that air should cover what ground cannot. -Understand own capabilities. Must use two screens for each person. Each screen is a different type of asset that one person covers. Splits attention. -Manage attention.
Opportunities/Improvising—Can you think of an example when you have improvised while planning asset deployment or noticed an opportunity to do something better? Interview: MS	I realized the unreliability of the "communications" asset. -Understand own capabilities.	Experts realize that the reliability of this asset is different than the reliability of the other three ground assets. -Understand own capabilities.	Novices misinterpret the reports of this asset. They have no insight into how reliability affects outcome of the game. -Understand own capabilities.
Self Monitoring—Can you think of a time when you realized you would need to change the way you were performing in order to get the asset deployment planning job done? Interview: MS	I know I need to double check when I see ambiguous information. Happened in a game this week. -Discriminate cues and patterns.	You should work through (mentally) all the available information on an area even when your available assets can't reach it on the next turn. -Assess situation (what do I know; how do I know it?)	Limiting your assets by letting yourself rely too heavily on one. Ignoring your other assets puts them in a position where you can't get them where you need them later. -Balance short and long term capabilities. There's a built-in bias that once

Yellow indicates cognitive task, function, or skill.

Probe	Example	Cues & Strategies	Why Difficult?
			you have looked at something twice, you might not want to send anything else to look at it. -Monitor own performance. People tend to concentrate on the upper right hand corner of the board for some reason. -Monitor performance.

SCUDHunt Knowledge Audit

Tasks*: CONSIDER ASSET RELIABILITY AND ALL DATA, & GENERATE STRIKE PLAN

Probe	Example	Cues & Strategies	Why Difficult?
Big Picture - Can you give me an example of what is important about the Big Picture for planning to generate a Strike Plan? What are the major elements you have to know and keep track of? Interview: MS	We had a problem in the game we did this week in the upper left hand grid. Had information, but we didn't look at it. We didn't look across all five turns.	Double-check or triple-check suspicious areas so that early suspicions stay fresh in your mind. -Attention management. -Discriminate cues and patterns. -Build a story . A strategy for looking across five turns is to flip across them all to get them in your mind rather than looking a long time at any one turn's results. -Build a story. -Discriminate cues and patterns. Remember each turn's interpretation. -Attention management. -Build a story.	You are never likely to have all three targets identified within one game. -Discriminate cues (don't wait for all 3 to come up; that pattern isn't going to happen). A lot of people take what they think is "black and white" info and focus on it. They believe a report that looks "clear" even when the asset is not reliable and they have been told it was not totally reliable during training. -Understand own capabilities. -Monitor own performance. There is a tendency to concentrate on the last couple of turns and ignore earlier turns. -Attention management. -Monitor own performance so as not to fixate. You may remember the conclusion of your turn, but not

Yellow indicates cognitive task, function, or skill.

* Three tasks from task audit consolidated. Some cognitive challenges for summing up info to generate Strike Plan are same as to deploy assets.

Probe	Example	Cues & Strategies	Why Difficult?
			the details of why you reached that conclusion. -Construct mental model When you look at the image of an old turn it reminds you of your conclusion, but it may not be seen as fresh information to react to in light of subsequent turns when you try to sum up across all the information. -Attention management. -Discriminate cues and patterns. -Construct mental model and check for violations of expectancies. -Monitor own performance to look for violated expectancies. Novices ignore the reliability of the assets; they ignore lots of details maybe to make information manageable. Such as they act like all assets are equally reliable. -Understand own capabilities. -Discriminate cues and patterns to manage

Yellow indicates cognitive task, function, or skill.

Probe	Example	Cues & Strategies	Why Difficult?
			information.overload.
Big Picture - Can you give me an example of what is important about the Big Picture for the planning to generate a Strike Plan? What are the major elements you have to know and keep track of? Interview: DD	Never saw a good Strike Plan in his limited experience. A negative example was watching a game and on a given turn, both the subject and the partner had put assets on the same square with results being a red X from both assets. They didn't follow through with this finding. Not sure why. Ignored the fact that once you find a SCUD, it is in the same place throughout the game. -Understand enemy capabilities and behaviors.	When two assets return a red X and one is highly reliable, you can rely on this to be a target. -Understand own capabilities. -Discriminate cues and patterns. Go back to previous results and refresh your memory on what you found earlier. -Discriminate cues and patterns. -Build a story. -Monitor for violated expectancies. Have assets cover the whole board as quickly as possible and then use higher reliability assets (ground assets) to confirm. -Envision goals and plans. After the first turn the priority is converging evidence. -Envision goals and plans.	Novice may get fixated on a current search and ignore previous findings. -Monitor own performance. -Attention management. Novices may believe SCUDs can move during the game and not realize when they have a firm target. -Understand enemy capabilities. In our game setup each player has to control two on screen boards. Switching back and forth is difficult. A full display of all that one had to attend to would keep the mechanics of the game from interfering with the thought processes during play. -Manage attention. On the Strike Plan, you have to do it twice exactly the same—

Yellow indicates cognitive task, function, or skill.

Probe	Example	Cues & Strategies	Why Difficult?
		Ground assets are very limited in their movement, but much more reliable (except "Commo Intel.") SEALS (ground asset) can only enter on the edge of the board. SpecOps (ground assets) can drop in other places, and can more easily be used to confirm a questionable air finding. -Understand own capabilities. Indication of an asset killed in action (skull and crossbones) is something worth checking. -Discriminate cues and patterns.	one for each board you control. We supplied a cheat sheet to help take the cognitive burden off the player for this. -Manage attention.
Big Picture—Can you give me an example of what is important about the Big Picture for planning to generate a Strike Plan? What are the major elements you have to know and keep track of? Interview: FJ	What assets returned what information is critical to keep track of. You can know that about your own assets, but have to coordinate with partner to find out what assets they used to get what pieces of data.	Review the findings for all turns looking for red Xs and where assets were killed or extracted. -Discriminate cues and patterns. -Build a story over time. Look at squares near where something was killed or extracted for activity there. (Especially killed.)	You can have mixed results over turns such as a red X on one turn and only a ? in the same location on another turn. Consider reliability to interpret. -Understand own capabilities. -Construct mental models. Novices see a red X and take it as a definite target. Novices don't check reliability of assets that their partner used.

Probe	Example	Cues & Strategies	Why Difficult?
		-Discriminate cues and patterns. Attend mainly to grid squares that have returned a red X from an asset. Look at that area and find out what assets were used to determine reliability of the report. Consider it a target if the asset has high reliability. -Discriminate cues and patterns. If there are no red Xs, nothing killed or extracted anywhere, look for multiple question marks as the information in a grid. Check those out in terms of what assets returned that information. It is highly likely that multiple ??s are a target if more than one type of asset returned a ?. Consider reliability of the assets used. -Discriminate cues and patterns. -Construct mental models. -Build a story.	Can only be done by coordinating with partner. -Understand own capabilities. On all Strike Plans (not just fifth and final) novices tend to think that the targets are actually being fired on. Strike Plan 1-4 is just to give your idea of where you think the targets are so far. They are not fired. Novices tend to think all Strike Plans are fired and that the firing is like an asset. If I fired three times at that grid square, there can't be anything there. Even when trained that this is not the case. Practice game in training is only one turn long and the first and only Strike Plan is fired. This element of training may be causing novices to think all plans are fired and to factor that into their thinking of what targets are still out there over the course of the game. -Understand own capabilities.

Yellow indicates cognitive task, function, or skill.

Probe	Example	Cues & Strategies	Why Difficult?
Self-monitoring - Can you think of a time when you realized you would need to change the way you were performing in order to plan a strike plan? Interview: DD			One pair of subjects seemed to misinterpret the instructions. The instructions were to submit a Strike Plan after every turn just to indicate their ideas at the time of where the enemy was. Only Strike Plan 5 is executed. They seemed to believe that every plan was fired and therefore they were using this for information, i.e., there can't be anything in that square anymore if I have bombed it already. -Understand own capabilities.

Yellow indicates cognitive task, function, or skill.

Probe	Example	Cues & Strategies Coordinate with partner	Why Difficult?
Big Picture - Can you give me an example of what is important about the Big Picture collaborating? What are the major elements you have to know and keep track of? Interview: MS	We had a problem in the game we did this week in the upper left hand grid. But we didn't look at it. We didn't look across all five turns.	Get your partner to re-look at the old findings. Find out which asset produced which result. You know that about your own findings only and must ask partner to assess reliability of their findings. -Story building. Maybe run through all the options with your partner. -Envision goals and plans. -Define roles and functions.	You could believe that in getting your partner to re-look at the old information, you have to get them to answer a lot of questions about the previous turns and the process could be perceived as annoying or badgering. You don't want to bother your partner. -Define roles and functions. Some people don't collaborate AT ALL. They do everything on their own and just notify partner of the minimum "OK. I'm finished." -Define roles and functions.
Job Smarts - When you collaborate are there ways of working smart or accomplishing more with less that you have found especially useful? Interview: MS	Thinking out loud during voice communications. Noticed really good collaboration came from people in our experiment who were friends before they came in. They even sent each other social comments over the chat function. So they were much less reluctant to generally ask for whatever information they needed.	Run through your logic and have your partner listen, i.e., model your ideas to your partner. Have them listen for flaws in your logic. -Story building. -Construct mental models. Ask the partner a straight out question—what asset did you use for X and how reliable is it? -Understand own capabilities. Experts could model thoughts for a novice when they are paired.	Novice might wait for you to present your conclusions to them and then just agree if they think you are better at this than they are.
Job Smarts – When you collaborate are there ways of working smart or accomplishing more with less that you have found especially useful? Interview: FJ	In the middle of the game (say turn 3), you should have a coordinated search plan going on with your partner. -Envision goals and plans.	One partner searches edges and one searches middle of search area. -Envision goals and plans. -Define roles and functions. To coordinate you can ask first where do you think we should go? -Envision goals and plans. You can make a proposal like	Novice doesn't know what partner's assets can do even with training. -Understand own capabilities. Novices don't coordinate.

Yellow indicates cognitive task, function, or skill.

Coordinate with partner

Yellow indicates cognitive task, function, or skill.

Appendix B

Cognitive Frameworks

Sample of Cognitive Model

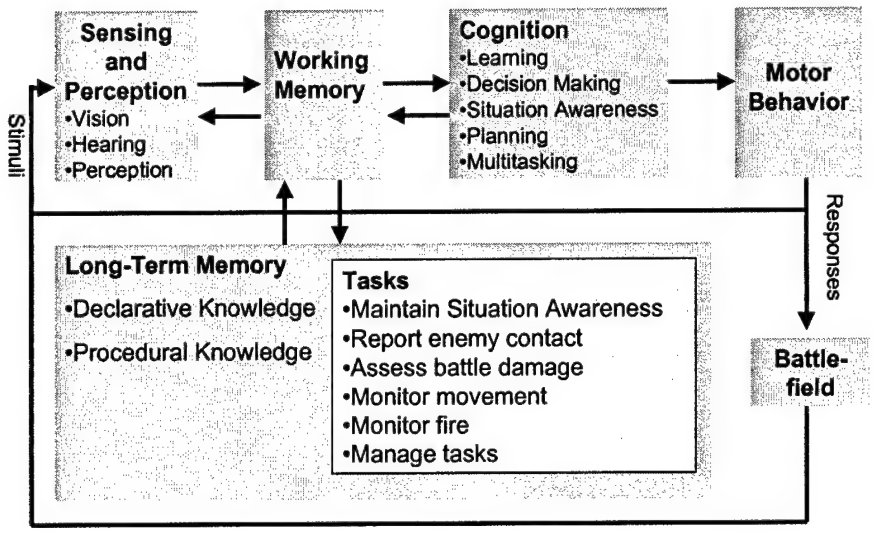

Figure B1. Typical stage model (semantic or conceptual) (from Pew & Mavor, 1998).

Pew, R. W., & Mavor, A. S. (Eds.). (1998). *Modeling human and organizational behavior: Application to military simulations*. Washington, D.C.: National Academy Press.

Training Objectives for Firefighter Team Decision Skills Training

(Harris, D., Malek, D. A., Ross, K. G., & Thordsen, M. L. (2002). *Developing a scenario-based training pedagogy for distributed teams* (Final Report for Contract #F33615-02-M-6011 prepared for the Air Force Research Laboratory, Mesa, AZ). Fairborn, OH: Klein Associates Inc.)

Terminal Objectives:

During operations, the team must be able to*

- Define roles and functions in relation to the current situation
- Compensate to fill gaps
- Assess the situation
- Envision goals and plans
- Balance immediate concerns and more distant objectives
- Balance a range of factors in decision making to avoid trying to deal with too many factors or fixating on too few.

Enabling Training Objectives:

Each team member must

- Manage attention
- Make perceptual discrimination among subtle cues and patterns—typical and anomalous
- Understand the team's/organization's capabilities
- Understand enemy capabilities (fire is the enemy in this case)
- Construct mental models of cause and effect
- Understand how own actions effect others

*These objectives assume that the training participant is proficient in the technical aspects of his or her job.

Matrix of Cognitive Skills

Cognitive Skills	Metacognitive Skills
Patterns • Recognize known patterns of components in a domain in a given situation/across situations in one domain, given complete information. • Infer known patterns that partial information may be part of in a given situation. • Infer additional components of patterns when partial information is given. **Example:** Scouts indicate the presence of the lead element of a large enemy unit. Scouts may indicate the presence of the lead element even in the absence of any other confirming information.	**Attention management** • Recognize high payoff information as a result of the application of cognitive skills (the story and expectancies generated) in a given situation. • Manage interruptions by completing the development of a story line, returning to generation of expectancies consistent with that story line, and continuing to assess new information in the context of the story line. **Example:** My story indicates that the enemy are behind what I believed was the friendly front line, therefore the appearance of a large fuel tanker truck in the north is important information.
Mental models • Recognize mental models in a domain across situations: i.e., how components interact to cause outcomes, given complete information. • Construct assumptions about how components can interact given incomplete information. **Example:** If we fire on scouts, they will alert the larger enemy element. The large fuel tanker coming from the north indicates that a large enemy unit is already positioned to our north.	**Uncertainty management** • Recognize irrelevant information as a result of the application of cognitive skills in a given situation. • Actively assess one's patterns, mental models and affordances to test the robustness of the predictions made by one's story. **Example:** Reports on displaced citizens clogging the road behind me are not useful in refining the story. Assessing the probability as high in a given situation (such as night or mud), strengthening the decision for action based on a salient affordance.
Affordances • Identify affordances (what is possible and not possible in the situation) that result from those mental models in a given situation. **Example:** It is possible for me to get a tank company to the top of that hill in five minutes. It is possible for one friendly tank company to defeat 30 enemy tanks when they are laagering.	**Adjustment mindset** • Evaluate the story that one has built or actions on is taking based on that story in order to accommodate new information and avoid fixating on a limited or erroneous interpretation. **Example:** Evaluating one's model of the enemy when one realizes that it was too static.

Story-building • Synthesize a story from patterns, mental models, and affordances in a given situation to interpret what is happening given complete information or various levels of incomplete information. • Synthesize a story to predict what could/will happen in order to generate expectancies. **Example:** If I attack the scouts without a plan to handle the brigade beyond them, I will generate a losing situation for my unit.	
Expectancies • Evaluate situation features to detect anomalies and violations of the expectancies in the constructed story in order to refine predictions. **Example:** The unexpected enemy presence forces our counterattack to begin earlier than we anticipated even though we have not gotten those explicit orders or intel from higher HQ.	

Preliminary List of Cognitive Skills

MAJOR CLASSIFICATION	FUNCTION
SENSORY INPUT	VISUAL, AUDITORY, TACTILE, VESTIBULAR, CHEMICAL
PERCEPTUAL PROCESSING	VISUAL (Object, Face, Space/Motion), AUDITORY, TACTILE, VESTIBULAR, CHEMICAL
SHORT-TERM MEMORY	ATTENTION DISTRIBUTION (Sustained, Selective, Divided) WORKLOAD CAPACITY (Single/Dual Task) PRE-ATTENTIVE PROCESSES (Perceptual, Conceptual) AUTOMATIC PROCESSES (Motor, Non-Motor)
WORKING MEMORY	LANGUAGE (Written, Spoken) SITUATION AWARENESS DECISION MAKING PLANNING TASK MULTIPLEXING VISUAL-MOTOR CONTROL MANIPULATING OBJECTS SPATIAL MANIPULATION MATHEMATICAL MANIPULATION PROBLEM SOLVING EPISODIC MEMORY PROCESSING PRODUCTION RULE SEQUENCING "HIGHER-LEVEL" COGNITIVE PROCESSES (Decision Making, Uncertainty Management, Mental Stimulation, Sensemaking, Situation Awareness, Attention Management, Problem Detection, Planning, Option Generation) (other metacognitive processes)
LONG-TERM MEMORY	STORAGE (Episodic, Procedural) RETRIEVAL (Episodic, Procedural)
MOTOR BEHAVIOR	PRECISION COORDINATION

Appendix C

Team Function, Task Roles, and Communication Frameworks

Name of Role	Description of Role	air12ac1 statements	Other Additional Statements
Task Roles			
Initiating	Proposing new ideas, goals, plans of action, or activities; orienting; prodding the team to greater activity; defining the position of team in relation to external structure or goal; offering suggestions and approaches.	We have our two-minute warning, I will attack the middle section.	
Elaborating	Clarifying ideas or suggestions; expanding on ideas or suggestions; developing a previously expressed idea; providing examples, illustrations, and explanations.	The middle will work. For example, we could take C4 and C5.	
Coordinating	Integrating; putting together parts of various ideas; organizing the team's work; promoting teamwork and cooperation.	I could attack the right side, but not column 5 and if you want you can attack the top left.	
Summarizing	Pulling work and ideas together; orienting the team; reviewing previous statements; reminding the team of items previously mentioned or discussed.	Okay, so we are saying that we should hit C1, 2 and 4.	
Recording	Keeping track of the team's work; keeping team records, preparing reports and minutes; serving as a team secretary or historian.	I'll keep track of what we are doing.	
Evaluating	Critiquing ideas or suggestions; expressing judgments on the merits of information or ideas; proposing or applying criteria for evaluating information.	Are you sure you want to attack C2? What about C1?	
Giving or Seeking Information	Presenting data; offering facts and information, evidence, or personal experience relevant to the team's task; asking others for facts and information, evidence, or relative personal experience; asking questions about information provided by others; requesting evaluations; asking if the team is reaching consensus.	Yeah, C4 looks like a target, and so does C2 possibly.	
Opinion Giving	Stating beliefs, values, interpretations, judgments; drawing conclusions from facts and information.	I think there is something down there!	
Clarifying	Interpreting issues; making ambiguous statements more clear; asking for examples or further clarification.	E3 looks suspicious, and D2 also.	
Consensus Testing	Asking if an apparent team decision is acceptable to all; suggesting that an agreement may have been reached and asking for verification of that.	Is everyone okay with this course of action?	
Proposing Procedure	Suggesting an agenda of issues, or a decision-making method; proposing a procedure to follow.	Why don't we examine one quad at a time?	

Name of Role	Description of Role	air12ac1 statements	Other Additional Statements
Team Maintenance Roles			
Encouraging	Praising, expressing warmth, support, and appreciation; recognizing the value of others' contributions; indicating positive feeling toward team members; reinforcing team unity and cohesiveness.	You are doing a good job!	
Supporting	Agreeing or expressing support for another's belief or proposal; following the lead of another member; accepting another's suggestions and contributions.	That is a great idea!	
Harmonizing	Helping to relieve tension; mediating differences; reducing secondary tension by reconciling disagreement; suggesting a compromise or a new acceptable alternative; working to reconcile angry members.	Hey, you two, we can compromise on this and hit both. We have enough turns.	
Gatekeeping	Keeping communication channels open; helping "quiet" members get the floor and be heard; suggesting turn taking or a speaking order; asking someone to offer a different opinion.	Air4, we haven't heard from you, what are you thinking?	
Process Observing	Making comments on how the team is working, how the members are coordinating and working together.	We are really working well together!	
Setting Standards	Helping to set goals and standards for the team; assisting in setting norms or making norms explicit; suggesting rules of behavior for members; challenging unproductive ways of behaving; giving a negative response when another violates a rule or norm.	We want to get this done with the highest score.	
Tension Relieving	Using humor, joking or otherwise relieving tension; helping new members feel at ease; reducing status differences; encouraging informality; stressing common interests and experiences within the team; developing team narratives, themes, and fantasies to build a common spirit and bond or to test a tentative value or norm.	Why couldn't all maps look like this… it would make my job easier :)	

Name of Role	Description of Role	air12ac1 statements	Other Additional Statements
Self-Oriented Behaviors			
Blocking	Preventing progress toward team goals by constantly raising objections; repeatedly bringing up the same topic or issue after the team has considered and rejected it (it is not blocking to raise an idea or topic the team has not really considered); preventing the team from achieving consensus; refusing to go along with, accept, or support a team decision.	I don't agree. You are wrong, and I'm not going to do it!	
Being Aggressive	Criticizing, threatening other team members, being a "noble fighter" preventing collaboration.	You are really stupid. What the heck were you thinking?	
Withdrawing	Remaining indifferent, refusing to contribute; avoiding important differences; refusing to cope with conflicts; refusing to take a stand; covering up feelings; giving no response to comments.	[silence]	
Dominating	Interrupting, refusing to accept others' conclusions as being as valid as one's own, forcing a leadership role.	I'm sorry, but my plan is the only way to go, and it is the only way I'll go!	
Status or Recognition Seeking	Stage hogging, boasting, and calling attention to one's expertise or experience when not necessary to credibility or relevant to the team's task; game playing to elicit sympathy; switching subject to area of personal expertise.	I'm the Captain, and I know more than any of you, so I suggest you listen.	
Special-Interest Pleading	Demanding team time and resources for special interest pleading; constantly advocating for one's subteam or special interest; not allowing team influence over one's perceived self interests.	Look, what do you think of the F17. I'm working on that project now, and just looking for opinions from other people.	

Appendix D

Challenges to Distributed Communication in SCUDHunt Game

Name of Challenge	Description of Challenge	air12ac1	specops13aac1	intel13ac1	satellite12ac1
Exchanges	Miscommunications express themselves in failures of handoff. What is communicated when to whom. Questions for clarification unanswered. Frequent question for clarification of issues. Is there a process for verification of info, product?	I think there is something out there.//OK that's a place where there is not much going on then, right?//Oh I deployed my manned aircraft on one side and it reports nothing. I do not think there is anything on the far right side, do you?//This part does not matter, it's only the last strike that does. Mine was in the middle to bottom region.			
Goal Conflict	Individual's subgoals are in conflict with overall goal of team. Particularly critical in planning phase. In real time does the team realize they are encountering conflicting goals?	We only have 2 turns left and, and I cannot get a detail on the center very well because my UAVs keep on dying.			My UAVs keep getting killed near the bottom.

Name of Challenge	Description of Challenge	air12ac1	specops13aac1	intel13ac1	satellite12ac1
Synchronization Overhead	Synchronization breakdown, individuals do not have anything to do, sit around, do not participate in discussion or planning, resulting in inefficiency and dysfunction. Do not actively participate in conversations. Poorly coordinated efforts.				
Diagnostic Overhead	Team asks: "How well are we doing as a team?" Monitoring effectiveness and efficiency of team. Thinking and watching how well your team functions as a team. Example: watching each others workload and offering to compensate if necessary.				

Name of Challenge	Description of Challenge	air12ac1	specops13aac1	intel13ac1	satellite12ac1
Build and Maintain SA	Building and maintaining big picture of the mission. Where do all the players, their tasks and missions fit within the overall mission?	OK that's a place where there is not much going on then, right?//Yeah, there maybe something there but I do not think column 5 has anything.//Next time sure.// This part does not matter, it's only the last strike that does. Mine was in the middle to bottom region.// I am deploying across C, across E and down 1./ / It looks like those could be the ones.	Column 1 has question marks.//I will submit my plan Top left across looks good.//What part did you strike so I can strike somewhere else. //I think C1 and 2 and 4 should be our targets.	I will strike C1.//C2 and D2 also look suspicious.//I am thinking of attacking the middle section.//My Navy Seals did not report anything on the lower right level.//We have our 2 minute warning, I will attack the middle section.//I covered the two sides of the entire aquare.//A4 and B4 have question marks.//I could attack the right side but not column 5 and if you want you can attack the top left?// I am thinking of attacking the top left.//	E3 looks suspicious, and D2 also. There is a lot of possible targets, but not much is confirmed. My UAVs keep getting killed near the bottom.//OK, I have deployed my satellite on 1 and my UAV is next to it in 2.
Distributed SA	Gaining common ground among team members. Different members have different info needs. Find ways to parse out pieces of big picture. Sharing the appropriate level of information.	C4 looks definite.//Yeah, the problem is finding out where in column 1 the target is./ /I have made my strike plan. This next turn is our last.//	My vix is not showing anything in the middle (response to air12)	My Navy Seals did not report anything on the lower right level.//A4 and B4 have questions marks	
Rigidity	Flexibility to adjust existing plans in light of new opportunities. Reacting to dynamic environment.				